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**Fricke et al.**

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(54) **PIEZOELECTRIC PRINTHEAD ASSEMBLY WITH MULTIPLIER TO SCALE MULTIPLE NOZZLES**


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(Continued)


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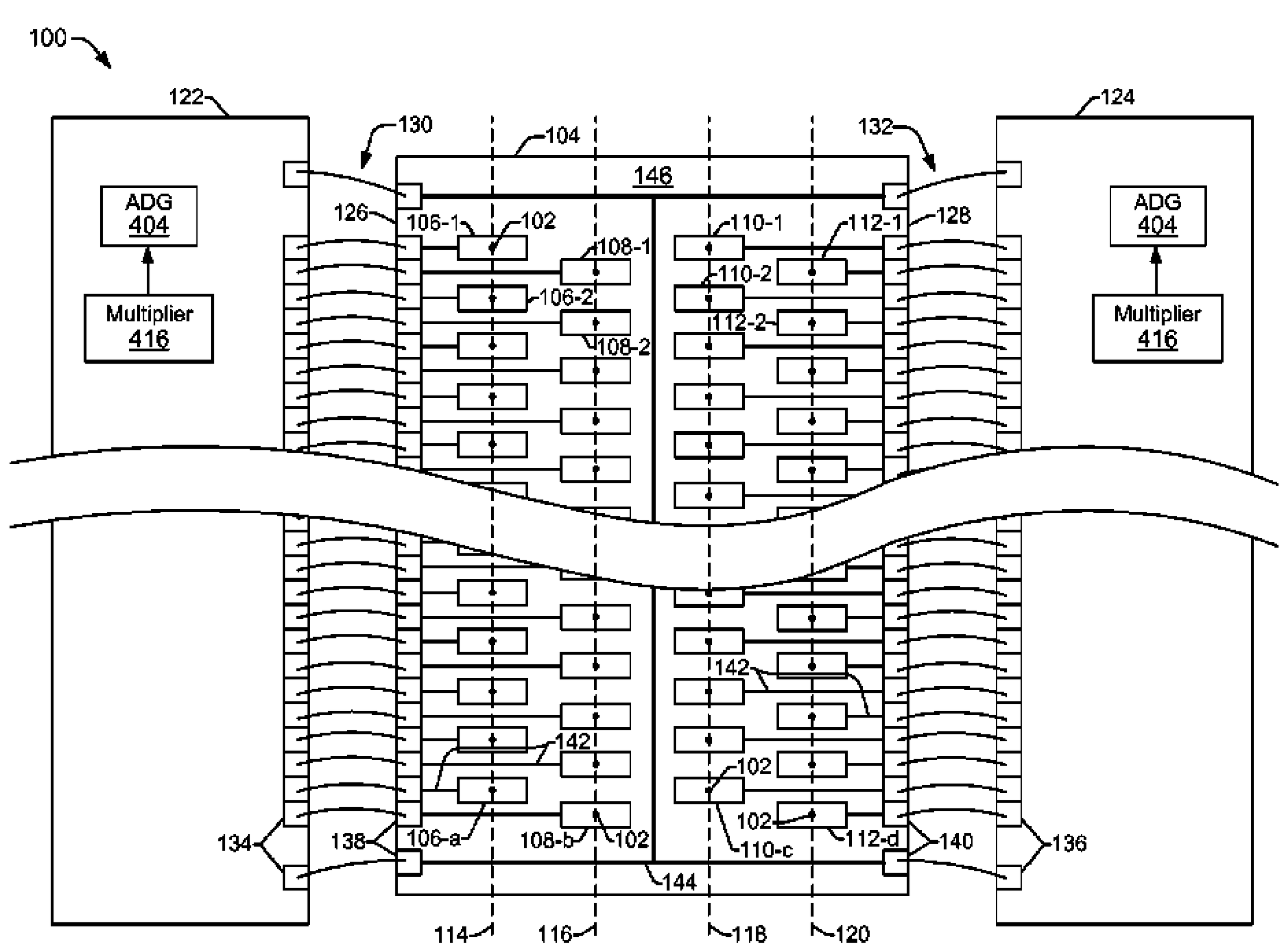
(57) **ABSTRACT**


In an example, a piezoelectric printhead assembly includes a micro-electro mechanical system (MEMS) die including a plurality of nozzles. An application-specific integrated circuit (ASIC) die is coupled to the MEMS die by a plurality of wire bonds, wherein each of the wire bonds corresponds to a respective nozzle of the plurality of nozzles. An arbitrary data generator (ADG) on the ASIC is to provide a digital data sequence, and a multiplier is to scale multiple nozzles of the plurality of nozzles.


**9 Claims, 6 Drawing Sheets**



(52) **U.S. Cl.**
CPC ....... ***B41J 2/04543*** (2013.01); ***B41J 2/04558*** (2013.01); ***B41J 2/04561*** (2013.01); ***B41J 2/04573*** (2013.01); ***B41J 2/04581*** (2013.01); ***B41J 2/14201*** (2013.01)

(58) **Field of Classification Search**
CPC .. B41J 2/04561; B41J 2/0456; B41J 2/04558; B41J 2/04573
See application file for complete search history.

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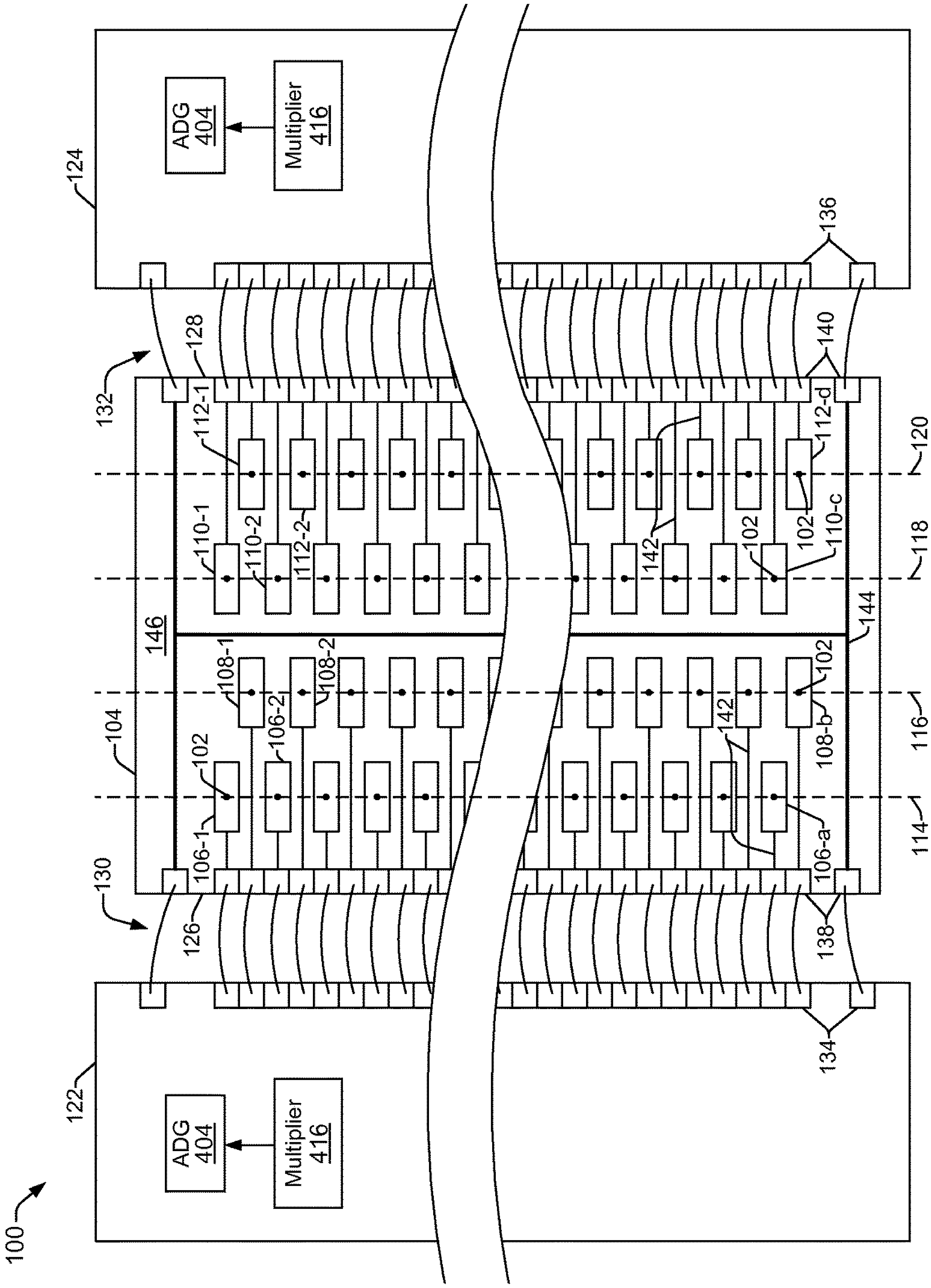

100
122
124
ADG
404
Multiplier
416
ADG
404
Multiplier
416
104
146
144
142
102
106-1
106-2
106-a
108-1
108-2
108-b
110-1
110-2
110-c
112-1
112-2
112-d
114
116
118
120
126
128
130
132
134
136
138
140

FIG. 1

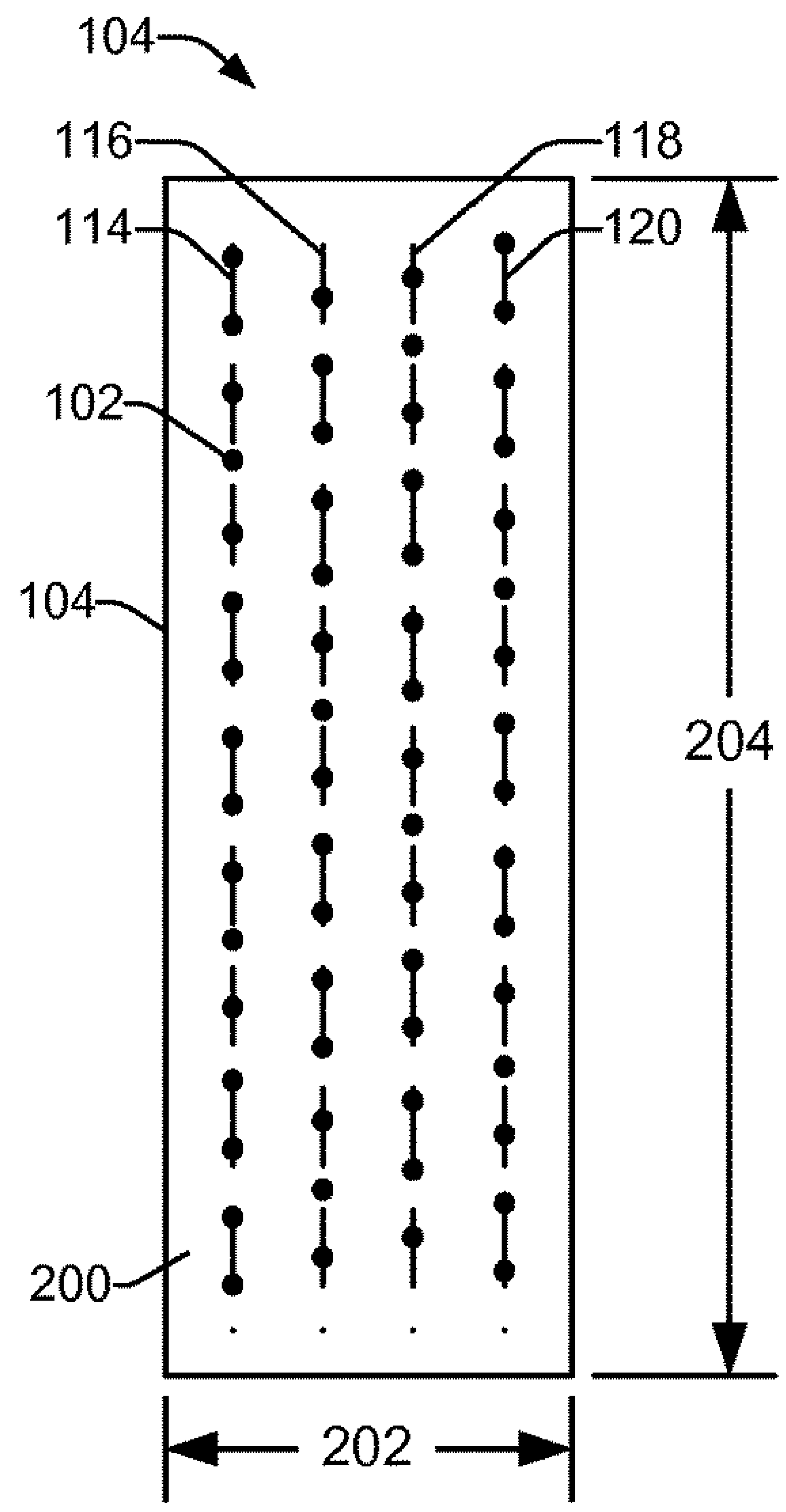

104
116
118
114
120
102
104
204
200
202

FIG. 2

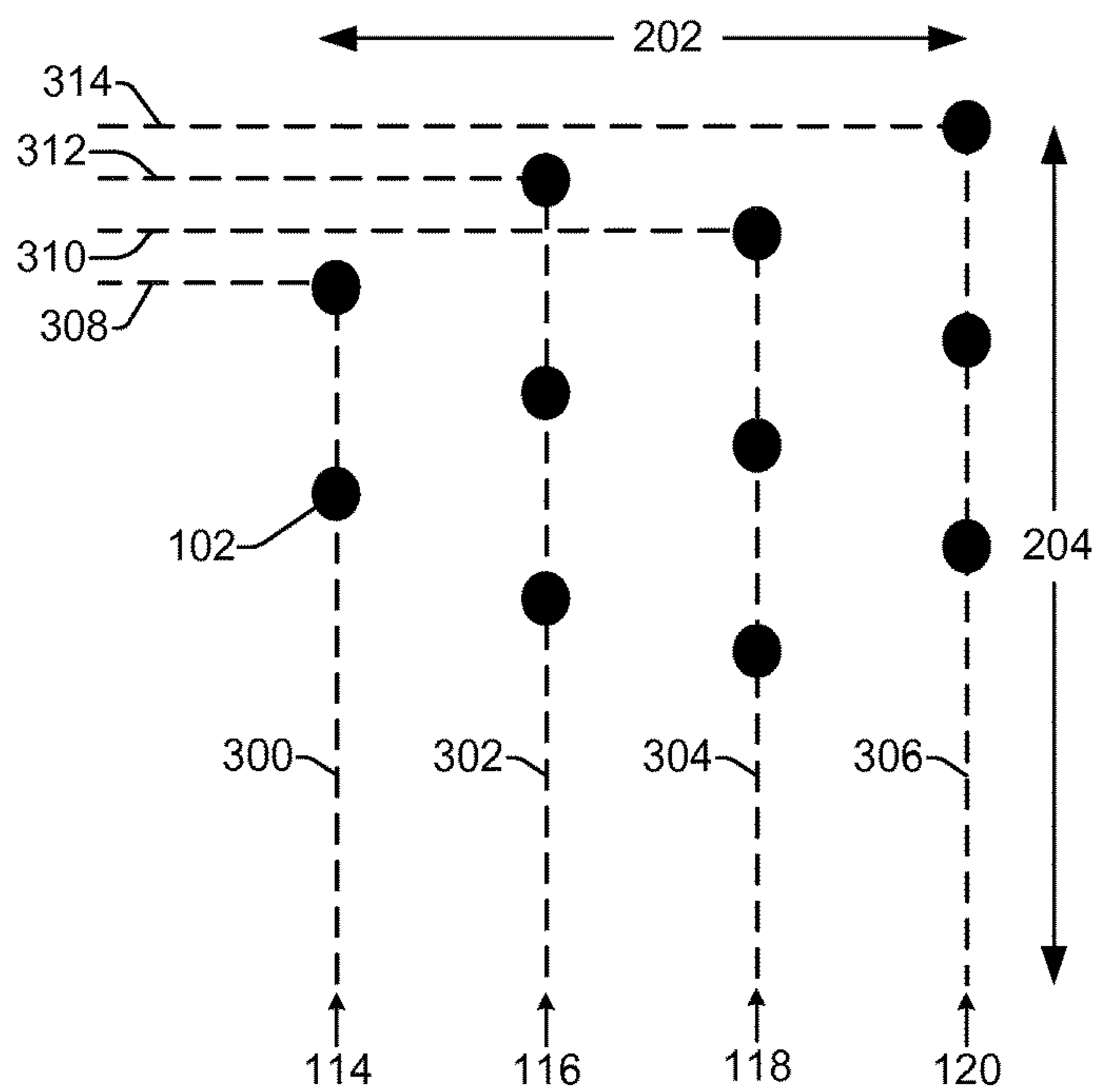
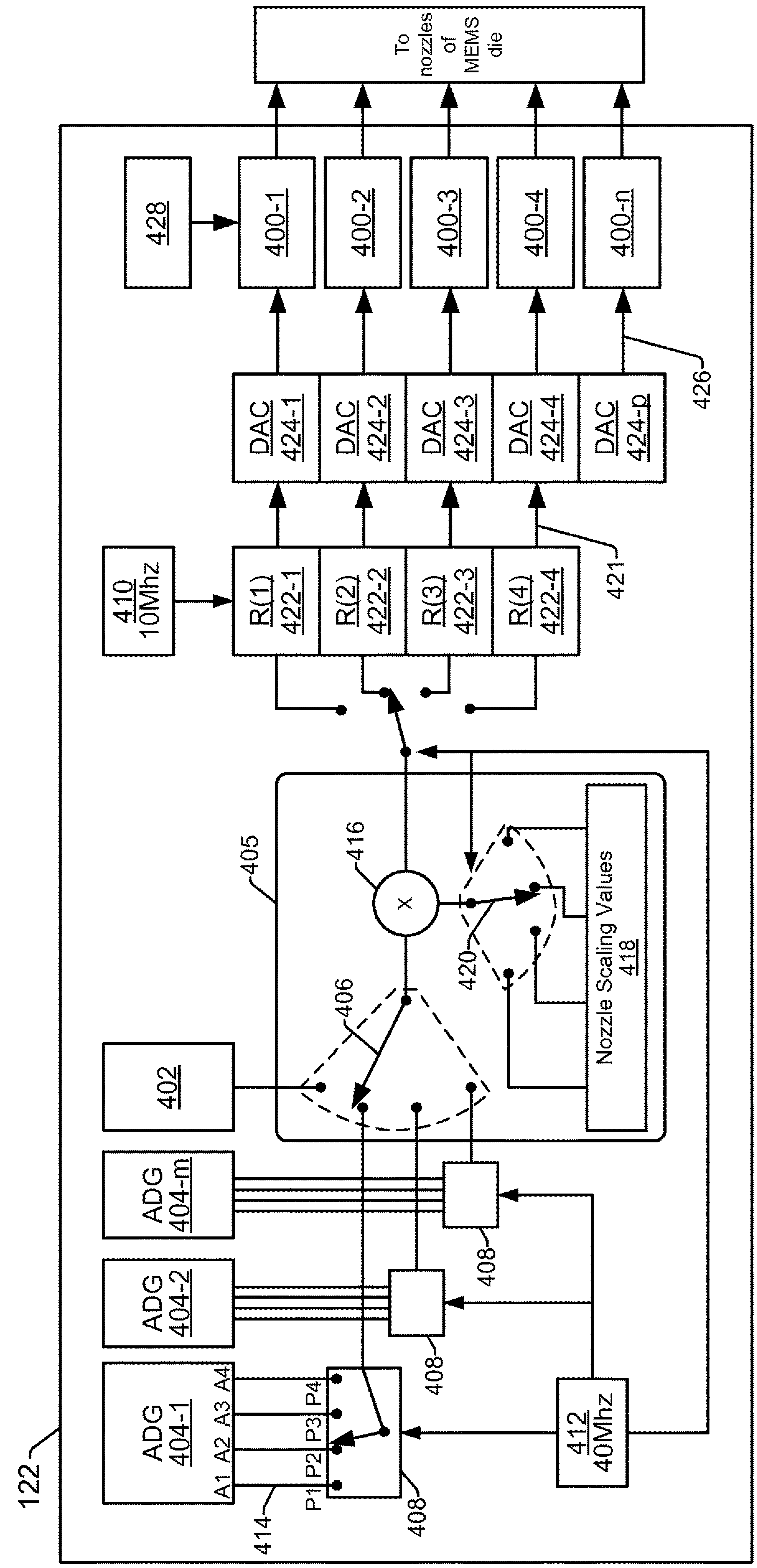

202
314
312
310
308
102
204
300
302
304
306
114
116
118
120

FIG. 3



To nozzles of MEMS die
428
400-1
400-2
400-3
400-4
400-n
DAC 424-1
DAC 424-2
DAC 424-3
DAC 424-4
DAC 424-p
426
410 10Mhz
R(1) 422-1
R(2) 422-2
R(3) 422-3
R(4) 422-4
421
405
416
×
420
Nozzle Scaling Values 418
406
402
ADG 404-m
ADG 404-2
ADG 404-1
A1 A2 A3 A4
P1 P2 P3 P4
408
408
408
414
412 40Mhz
122


FIG. 4

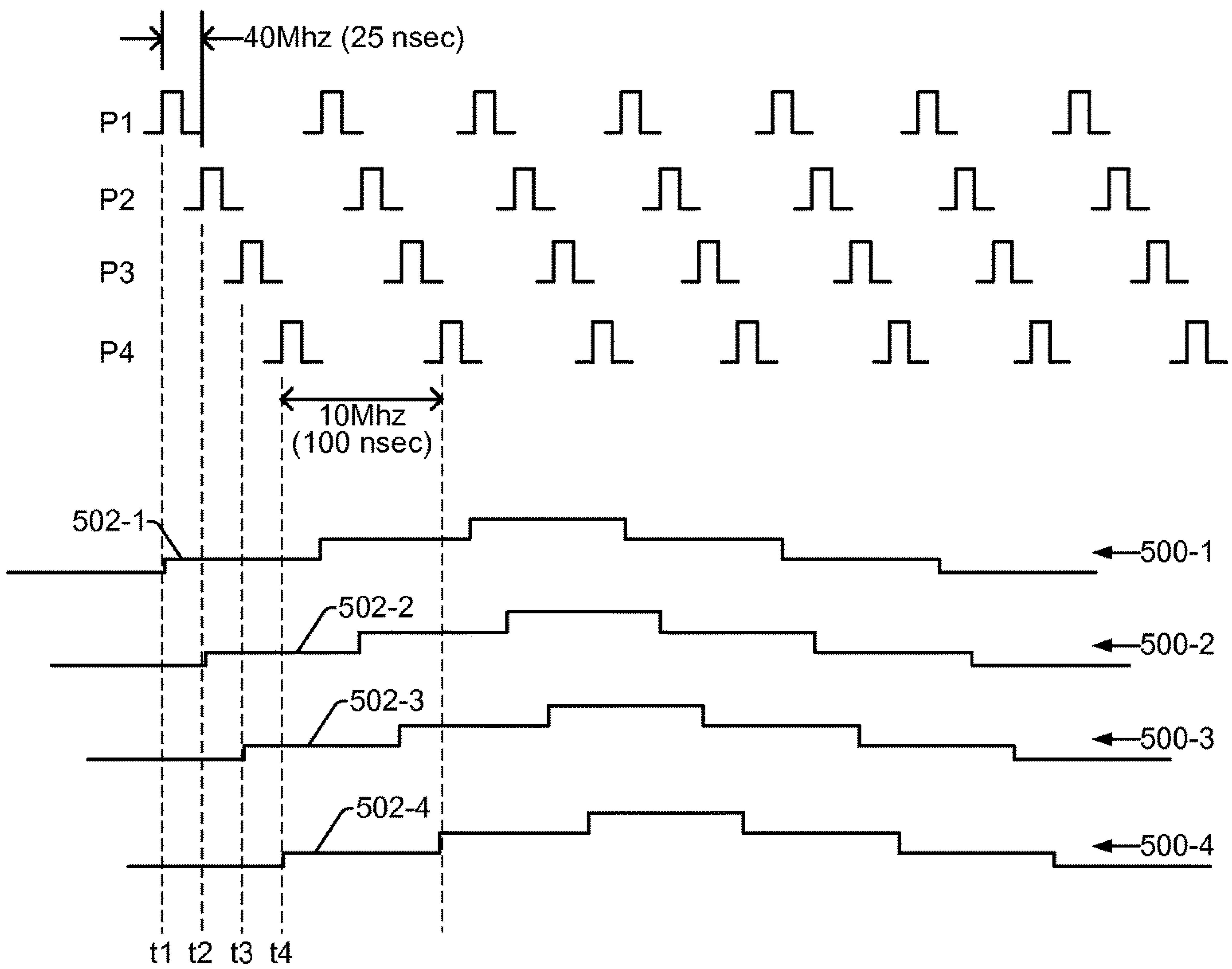

40Mhz (25 nsec)
P1
P2
P3
P4
10Mhz
(100 nsec)
502-1
502-2
502-3
502-4
500-1
500-2
500-3
500-4
t1
t2
t3
t4

FIG. 5

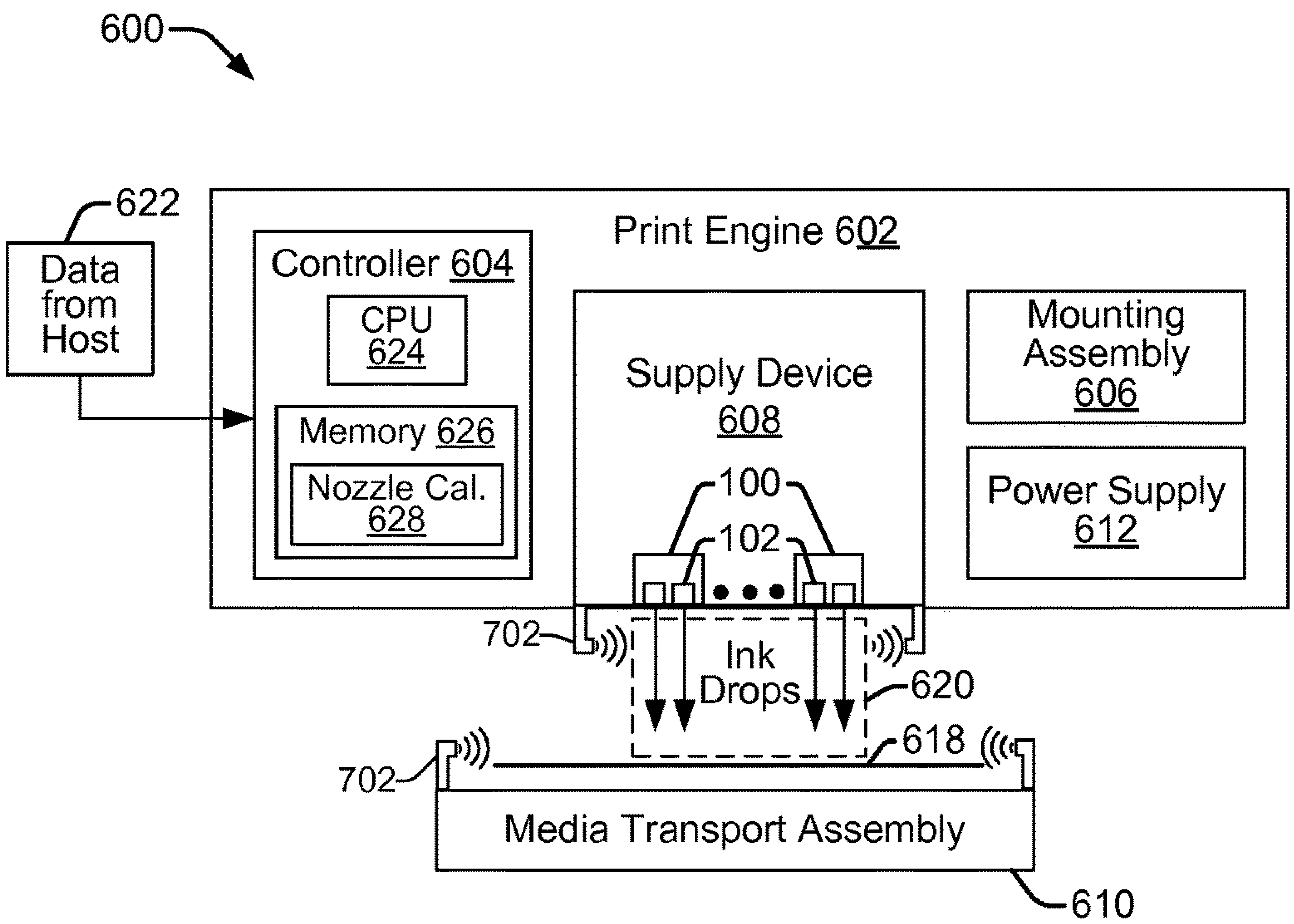

600
622
Data from Host
Print Engine 602
Controller 604
CPU 624
Memory 626
Nozzle Cal. 628
Supply Device 608
100
102
Mounting Assembly 606
Power Supply 612
702
Ink Drops
620
618
702
Media Transport Assembly
610

FIG. 6

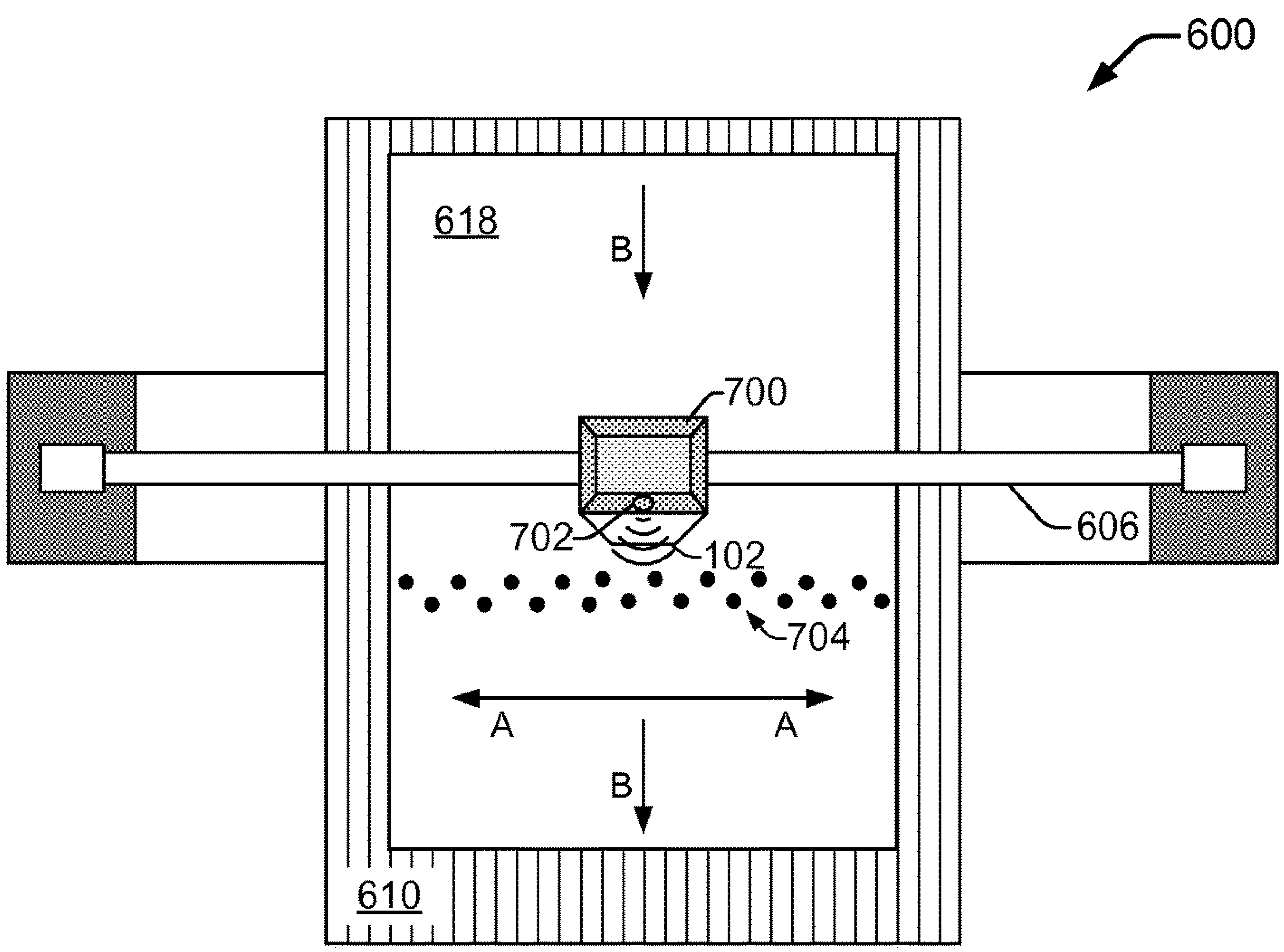

600
618
B
700
606
702
102
704
A
A
B
610

FIG. 7

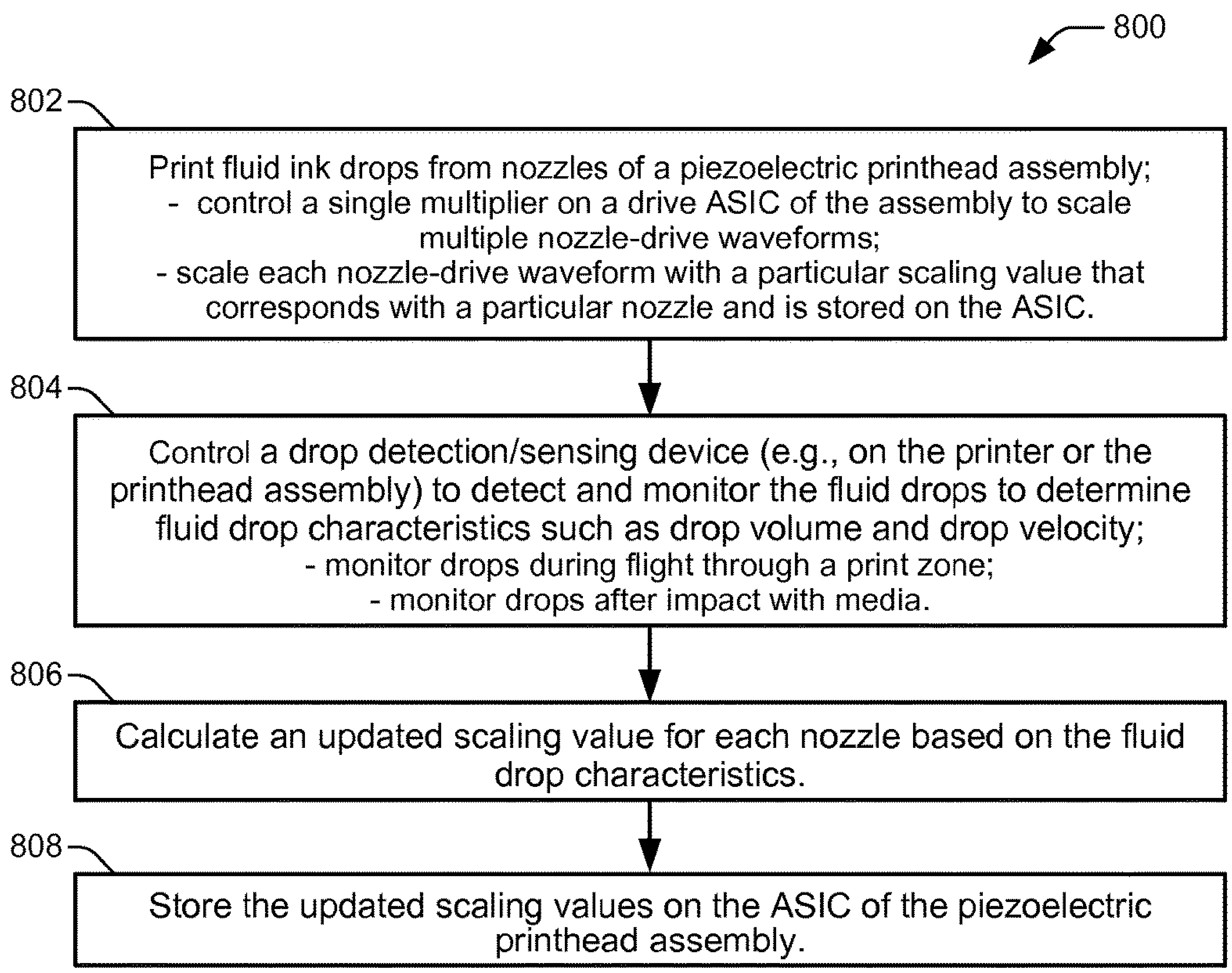

800
802
Print fluid ink drops from nozzles of a piezoelectric printhead assembly;
- control a single multiplier on a drive ASIC of the assembly to scale multiple nozzle-drive waveforms;
- scale each nozzle-drive waveform with a particular scaling value that corresponds with a particular nozzle and is stored on the ASIC.
804
Control a drop detection/sensing device (e.g., on the printer or the printhead assembly) to detect and monitor the fluid drops to determine fluid drop characteristics such as drop volume and drop velocity;
- monitor drops during flight through a print zone;
- monitor drops after impact with media.
806
Calculate an updated scaling value for each nozzle based on the fluid drop characteristics.
808
Store the updated scaling values on the ASIC of the piezoelectric printhead assembly.

FIG. 8

# PIEZOELECTRIC PRINTHEAD ASSEMBLY WITH MULTIPLIER TO SCALE MULTIPLE NOZZLES

## BACKGROUND

Fluid-jet printing devices eject printing fluid drops such as ink drops onto a print medium, such as paper. The ink drops bond with the paper to produce visual representations of text, images or other graphical content on the paper. In order to produce the details of the printed content, nozzles in a print head accurately and selectively release multiple ink drops as the relative positioning between the print head and printing medium is precisely controlled. Fluid-jet printing technologies include thermal and piezoelectric inkjet technologies. Thermal inkjet printheads eject fluid drops from a nozzle by passing electrical current through a heating element to generate heat and vaporize a small portion of the fluid within a firing chamber. Piezoelectric inkjet printheads use a piezoelectric material actuator to generate pressure pulses that force ink drops out of a nozzle.

## BRIEF DESCRIPTION OF THE DRAWINGS

Examples will now be described with reference to the accompanying drawings, in which:

FIG. **1** shows a portion of an example piezoelectric printhead assembly suitable for providing multiple delayed waveform signals to drive print nozzles on an example micro-electro mechanical system (MEMS) die;

FIG. **2** shows a portion of an example MEMS die such as the MEMS die of FIG. **1**;

FIG. **3** shows a plurality of nozzles in an example arrangement on a portion of an example MEMS die;

FIG. **4** shows example components of an example ASIC die, such as the ASIC die of FIG. **1**;

FIG. **5** shows a timing example of an example four phase read operation to read source data from a single ADG RAM;

FIG. **6** shows an example of an inkjet printing device suitable for implementing an example piezoelectric printhead assembly to provide multiple delayed digital data sequences from a single ADG RAM;

FIG. **7** shows an example of a scanning type inkjet printer suitable for implementing an example piezoelectric printhead assembly to provide multiple delayed digital data sequences from a single ADG RAM;

FIG. **8** shows a flow diagram that illustrates an example method corresponding with a nozzle calibration routine.

Throughout the drawings, identical reference numbers designate similar, but not necessarily identical, elements.

## DETAILED DESCRIPTION

Examples described herein relate to piezoelectric printhead assemblies and methods. More specifically, in some example assemblies, a drive ASIC (application specific integrated circuit) includes an arbitrary data generator (ADG) selectable to provide a digital data sequence used to construct multiple delayed (i.e., temporally offset) waveform signals for driving print nozzles. Multiple delayed digital data sequences are generated from the ADG source digital data sequence and the delayed digital data sequences are scaled with a voltage to compensate for mechanical and electrical variations of each nozzle. Driving print nozzles with multiple delayed waveform signals helps to reduce peak currents when firing multiple nozzles simultaneously.

A multiplier function can scale multiple nozzles by multiplying the delayed digital data sequences to provide a unique voltage scaled waveform for each nozzle. The multiplier function is clocked at a higher rate than the nozzle input update frequency (e.g. **4**$x$ the nozzle input update frequency), which allows the multiplier function to be utilized for multiple nozzles (e.g. one multiplier for 4 nozzles). Using a single ADG RAM to construct multiple delayed waveform nozzle-drive signals, as well as the multiplier function to scale waveforms for more than one nozzle, helps to preserve valuable area on the silicon die of the drive ASIC and enables a smaller form factor for the ASIC. This results in a reduced cost for the ASIC and a narrower print zone width for the printhead assembly, which helps to improve print quality. Among other advantages, example printhead assemblies described herein help to provide increased nozzle density, increased reliability, increased image quality, and/or increased printing speed, as compared to other piezoelectric printhead assemblies.

Piezoelectric printing is a form of drop-on-demand printing where a fluid drop (e.g., an ink drop) is ejected from a nozzle of a die when an actuation pulse is provided to the nozzle. For piezoelectric printing, the actuation pulse is provided as an electrical drive voltage to a piezoelectric material of the die. The piezoelectric material deforms in response to the actuation pulse, causing a fluid drop to be ejected from the nozzle.

Prior piezoelectric printhead assemblies used in some piezoelectric printers include a linear, or one dimensional array of nozzles located on a micro-electro-mechanical die. Such piezoelectric printhead assemblies can use a high power waveform amplifier that is located away from the micro-electro-mechanical die to mitigate the effects of the large amount of heat generated by the amplifier. The heat can be problematic because the viscosity of the fluids used for piezoelectric printing is affected by temperature and temperature fluctuations. The transfer of amplifier heat into the fluids can reduce image quality. For example, a rise in temperature of the fluid used in piezoelectric printing due to the waveform amplifier heat can cause undesirable drop size variation and/or undesirable placement of drops on the media. For these prior piezoelectric printhead assemblies, a drive waveform can be sent over a flex interconnect to a drive multiplexer coupled to a one dimensional array of nozzles located on the micro-electro mechanical die. In contrast to such piezoelectric printhead assemblies, example piezoelectric printhead assemblies disclosed herein include a micro-electro-mechanical system (MEMS) die with nozzles driven by multiple delayed waveform signals generated on an adjacent ASIC that is coupled to the MEMS die by wire bonds. As noted above, such printhead assemblies help to reduce peak currents which can reduce the amount of heat generated by waveform amplifiers. In addition, the example printhead assemblies enable a narrower print zone width and provide increased nozzle density, increased reliability, increased image quality, and/or increased printing speed.

FIG. **1** illustrates a portion of a piezoelectric printhead assembly **100** suitable for providing multiple delayed waveform signals to drive print nozzles **102** on a micro-electro mechanical system (MEMS) die **104**. The assembly **100** includes the MEMS die **104**, which is also commonly referred to as a printhead die **104**. The MEMS die **104** can include a number of piezoelectric materials **106-1**, **106-2**, . . . , **106**-*a*; **108-1**, **108-2**, . . . , **108**-*b*; **110-1**, **110-2**, . . . , **110**-*c*; and **112-1**, **112-2**, . . . , **112**-*d*. Reference letters a, b, c, and d, each represent an independent integer value. In some examples, a, b, c, and d, each have an equal integer value.

As shown in FIG. **1**, the piezoelectric materials **106-1**, **106-2**, . . . , **106**-*a*, can be associated with a first column **114** of nozzles **102**; the piezoelectric materials **108-1**, **108-2**, . . . , **108**-*b* can be associated with a second column **116** of nozzles **102**; the piezoelectric materials **110-1**, **110-2**, . . . , **110**-*c* can be associated with a third column **118** of nozzles **102**; and the piezoelectric materials **112-1**, **112-2**, . . . , **112**-*d* can be associated with a fourth column **120** of nozzles **102**. Each nozzle **102** can have a number of associated piezoelectric materials. Thus, an actuation pulse may be provided to a number of piezoelectric materials to eject a drop from a particular nozzle **102**.

The piezoelectric printhead assembly **100** can include a first application specific integrated circuit (ASIC) die **122** and/or a second ASIC die **124**. In some examples, the first ASIC die **122** and the second ASIC die **124** have a single, common, design. For example, the first ASIC die **122** and the second ASIC die **124** can have the same configuration incorporating like components prior to their being coupled to the MEMS die **104**. Thus, prior to ASIC dies **122** and **124** being coupled to MEMS die **104**, the ASIC dies **122** and **124** are interchangeable. This provides the additional advantage that a single type of ASIC die can be fabricated for use in the piezoelectric printhead assembly **100**. In some examples, ASIC dies **122** and **124** include an arbitrary data generator (ADG) **404** to provide a single digital data sequence, and a multiplier **416** to scale multiple digital data sequences generated from the ADG **404** by a particular scaling factor associated with a respective nozzle on the MEMS die **104**. In some examples, one of the ASIC dies **122** or **124**, is rotated 180 degrees relative to the other ASIC die, and is located transverse the MEMS die **104** relative to that ASIC die. Accordingly, a first ASIC die **122** can be coupled to a first side **126** of MEMS die **104**, and the second ASIC die **124** can be rotated 180 degrees relative to the first ASIC die **122** and be coupled to a second side **128** of the MEMS die **104**.

As shown in FIG. **1**, the first ASIC die **122** is coupled to the MEMS die **104** by a plurality of wire bonds **130**, and the second ASIC die **124** is coupled to the MEMS die **104** by another plurality of wire bonds **132**. The composition of the wire bonds **130** and **132** can include metals such as gold, copper, aluminum, silver, palladium, or alloys thereof, among others. The wires utilized for wire bonds **130** and **132** can have a diameter in the range of about 10 microns to 100 microns, for example. Forming the wire bonds **130** and **132** can include various bonding methods such as ball bonding, wedge bonding, compliant bonding, or combinations thereof, among others.

As shown in FIG. **1**, the first ASIC die **122** can include a plurality of wire bond pads **134**, the second ASIC die **124** can include a plurality of wire bond pads **136**, the MEMS die **104** can include a first plurality of wire bond pads **138** near a first side **126** of the die **104**, and the MEMS die **104** can include a second plurality of wire bond pads **140** near a second side **128** of the die **104**. The plurality of wire bond pads **134** and the first plurality of wire bond pads **138** can be used to couple the first ASIC die **122** to the MEMS die **104** with the plurality of wire bonds **130**. Similarly, the plurality of wire bond pads **136** and the second plurality of wire bond pads **140** can be used to couple the second ASIC die **124** to the MEMS die **104** with the plurality of wire bonds **132**.

As shown in FIG. **1**, the MEMS die **104** can include a plurality of traces **142**. The plurality of traces **142** couple the



first plurality of wire bond pads **138** to the piezoelectric materials associated with the first column **114** of nozzles **102** and the second column **116** of nozzles **102**, and they couple the second plurality of wire bond pads **140** to the piezoelectric materials associated with the third column **118** of nozzles **102** and the fourth column **120** of nozzles **102**. The MEMS die **104** also includes a ground **144** to which each of the piezoelectric materials associated with the first column **114** of nozzles **102**, the second column **116** of nozzles **102**, the third column **118** of nozzles **102**, and the fourth column **120** of nozzles **102**, can be coupled.

As mentioned above, the MEMS die **104** can include a first side **126** and a second side **128**. In some examples, the first side **126** and/or the second side **128** are perpendicular to a rear face **146** of the MEMS die **104**. In some examples, the first side **126** and/or the second side **128** are perpendicular to a shooting face of the MEMS die **104**, discussed further herein. In some examples, the rear face **146** and the shooting face are parallel to one another.

As shown in FIG. **1**, in some examples the first ASIC die **122** is adjacent to the first side **126** of the MEMS die **104**, and the second ASIC die **124** is adjacent to the second side **128** of the MEMS die **104**. Locating the first ASIC die **122** and the second ASIC die **124** adjacent to the respective sides of the MEMS die **104** can help to accommodate an increased wire bond density, as discussed further below.

In some examples, the first ASIC die **122**, the MEMS die **104**, and the second ASIC die **124** do not overlie one another. That is, the first ASIC die **122** does not overlie the MEMS die **104** or the second ASIC die **124**, the MEMS die **104** does not overlie the first ASIC die **122** or the second ASIC die **124**, and the second ASIC die **124** does not overlie the first ASIC die **122** or the MEMS die **104**. Thus, a planar cross section of the MEMS die **104** that is perpendicular to the first side **126** of the MEMS die and the second side **128** of the MEMS die **104** can be entirely located between the first ASIC die **122** and the second ASIC die **124**.

Using wire bonds **130** and **132** to respectively couple the first ASIC die **122** and the second ASIC die **124** to the MEMS die **104** can help to provide an increased nozzle density. Furthermore, using the wire bonds **130** and **132** to respectively couple the first ASIC die **122** and the second ASIC die **124** to the MEMS die **104** can quadruple a nozzle density as compared to other piezoelectric printers that utilize a flex interconnect to couple a multiplexer to a die. The use of flex interconnects cannot provide a high enough interconnect density to enable a nozzle density of the piezoelectric printhead assemblies disclosed herein.

FIG. **2** illustrates a portion of a MEMS die **104**, such as the MEMS die **104** shown in FIG. **1**. As shown in FIG. **2**, the MEMS die **104** can include a shooting face **200** and a plurality of nozzles **102**. In some examples the plurality of nozzles **102** can be arranged in a two dimensional array. As shown in FIG. **2**, the plurality of nozzles can extend in a crosswise direction **202** across the shooting face **200** and extend in a longitudinal direction **204** along the shooting face **200**. In some examples, the MEMS die **104** can include a first column **114** of nozzles **102**, a second column **116** of nozzles **102**, a third column **118** of nozzles **102**, and a fourth column **120** of nozzles **102**. While FIG. **2** shows four columns of nozzles extending along the longitudinal direction **204**, other examples can include a lesser or greater number of columns of nozzles. For example, in different implementations the MEMS die **104** may include two columns of nozzles or six columns of nozzles. In some examples, the MEMS die **104** has a nozzle density of at least 1200 nozzles per inch.

FIG. **3** shows a plurality of nozzles **102** in an example arrangement on a portion of a MEMS die **104**. As noted above, the plurality of nozzles **102** can extend in a crosswise direction **202**, and they can extend in the longitudinal direction **204**. As shown in FIG. **3**, nozzles in a first column **114** can be associated with a longitudinal axis **300**, nozzles in a second column **116** can be associated with a longitudinal axis **302**, nozzles in the a third column **118** can be associated with a longitudinal axis **304**, and nozzles in a fourth column **120** can be associated with a longitudinal axis **306**. In some examples, the longitudinal axis **300** can be separated from the longitudinal axis **302** by a distance ranging from about 0.0466 hundredths of an inch to about 0.0500 hundredths of an inch; the longitudinal axis **302** can be separated from the longitudinal axis **304** by a distance ranging from about 0.0600 hundredths of an inch to about 0.0667 hundredths of an inch, and the longitudinal axis **304** can be separated from the longitudinal axis **306** by a distance ranging from about 0.0466 hundredths of an inch to about 0.0500 hundredths of an inch.

As shown in FIG. **3**, nozzles in the first column **114** can be associated with a crosswise axis **308**, nozzles in the second column **116** can be associated with a crosswise axis **312**, nozzles in the third column **118** can be associated with a crosswise axis **310**, and nozzles in the fourth column **120** can be associated with a crosswise axis **314**. In some examples, the crosswise axis **308** can be separated from the crosswise axis **310** by a distance ranging from about 0.0004 hundredths of an inch to about 0.0033 hundredths of an inch; the crosswise axis **310** can be separated from the crosswise axis **312** by a distance ranging from about 0.0004 hundredths of an inch to about 0.0033 hundredths of an inch, and the crosswise axis **312** can be separated from the crosswise axis **314** by a distance ranging from about 0.0004 hundredths of an inch to about 0.0033 hundredths of an inch.

FIG. **4** illustrates components of an example ASIC die **122**, such as ASIC die **122** and/or ASIC die **124** as discussed above with regard to FIG. **1**. As mentioned above, in some examples, a first ASIC die **122** and a second ASIC die **124** can have a single design that is common to each die. Thus, a second ASIC die **124** can incorporate the same components as the ASIC die **122** illustrated in FIG. **4**.

The ASIC die **122** can include a number of driver amplifiers **400** (illustrated as amplifiers **400-1**, **400-2**, **400-3**, **400-4**, . . . , **400-*n***, where n is an integer value). For instance, n can have a value equal to one half of a number of nozzles **102** of a MEMS die **104** to which the ASIC die **122** is wire bonded. In some examples, a total number of a first plurality of wire bonds coupling an ASIC die **122** to a MEMS die **104** can be equal to a total number of a second plurality of wire bonds. For instance, a MEMS die **104** having 1056 nozzles **102**, can be coupled to a first ASIC die **122** and to a second ASIC die **124**. Thus, the first ASIC die **122** can include 528 driver amplifiers **400** and the second ASIC **124** die can also include 528 driver amplifiers **400**. In such an example, the ASIC die **122** can control a first half of the nozzles **102** of a MEMS die **104** and a second ASIC die **124** can control a second half of the nozzles **102** of the MEMS die **104**.

Fluid (e.g., ink) ejected from the nozzles **102** can be sensitive to thermal variation. For instance, a change of one degree Celsius can cause undesirable drop size variations and/or undesirable placement of drops on the media resulting in noticeable print defects. As mentioned, the ASIC dies **122** and **124** as shown in FIG. **1** are wire bonded to a MEMS die **104**. Because the ASIC dies are wire bonded to the MEMS die, the ASIC dies are located in close proximity (i.e., adjacent) to the MEMS die. To help reduce print defects, the driver amplifiers **400** can be low power amplifiers. Using low power amplifiers **400** can help to maintain the printing fluid at a constant temperature that does not increase by one degree Celsius or more due to heat generated by the driver amplifiers. Accordingly, in some examples, the driver amplifiers **400** have a constant bias power dissipation in a range from about 0.5 milliwatts to about 3.0 milliwatts. In other examples, the driver amplifiers **400** can have a constant bias power dissipation of about 1.0 milliwatts.

The ASIC die **122** can include a rest voltage component **402**. The rest voltage component **402** enables nozzles that are not being fired to be maintained at a constant, rest voltage. In addition to rest voltage component **402**, the ASIC die **122** can include a number or arbitrary data generators (ADG) **404** (illustrated as ADG's **404-1**, **404-2**, . . . , **404-*m***, where m is an integer value). In some examples, m is in a range from 16 to 32. In some examples, individual nozzle control and/or nozzle-drive waveform generation is provided by ASIC die **122** with the assistance of a conditioner unit **405**. The conditioner unit **405** can receive digital input such as digital data sequences from the number of ADG's **404** and the rest voltage component **402**. The conditioner unit **405** can include an ADG selector **406** to select an available digital data sequence provided by a particular ADG **404**. The digital data sequence selection (i.e., the ADG **404** selection) can be based on current pixel data, future pixel data, past pixel data, and/or calibration data, which can be provided to the ADG selector **406**. For instance, the ADG selector **406** may use a two bit data protocol for specifying if a specific arbitrary digital data sequence will be selected for a particular nozzle **102**. As an example, "00" may indicate rest voltage; "01" may indicate selection of an ADG **404** having a digital data sequence that enables a single drop nozzle-drive waveform for firing; "10" may indicate selection of an ADG **404** having a digital data sequence that enables a double drop nozzle-drive waveform for firing; and "11" may indicate selection of an ADG **404** having a digital data sequence that enables a triple drop nozzle-drive waveform for firing. Other configurations are also possible. For example, in another implementation, "01" may indicate selection of an ADG **404** having a digital data sequence that enables a double drop nozzle-drive waveform, and so on. In some examples, current pixel data can correspond to "0" or "1" for a present firing cycle, past pixel data can correspond to pixel times that have already occurred, and future pixel data can correspond to a pixel that has not yet occurred.

Each ADG **404** provides a particular digital data sequence that can be used as source data to construct multiple, identical, temporally offset, digital data sequences (i.e., identical digital data sequences that are delayed in time with respect to one another). The temporally offset data sequences can be subsequently conditioned and constructed (e.g., through driver amplifiers **400**) into nozzle-drive waveforms that can be used to drive print nozzles **102** on a MEMS die **104** in a manner that delays the firing of nozzles with respect to one another. Using temporally delayed versions of the same nozzle-drive waveform to drive different nozzles **102** can help to reduce the number of nozzles firing simultaneously, and thereby reduce the peak currents drawn by the printhead assembly **100**. In general, the ejection of fluid from a nozzle **102** is influenced by a nozzle-drive waveform when the waveform is applied to deflect the piezoelectric material corresponding to that nozzle. Nozzle-drive waveforms can have different voltages, widths, and/or shapes that can be varied to provide different drop characteristics, such as drop weight and velocity, for example. Different nozzle-drive waveforms, conditioned and constructed from different digital data sequences generated by different ADG's **404-1**, **404-2**, . . . , **404-*m***, may each correspond to a unique combination of voltage, pulse width, time delay, and/or shape.

In some examples, an ADG **404** is provided in a 256×8 bit RAM (random access memory) storage component having 256, eight-bit voltage values. Thus, the digital source data stored in each ADG RAM **404** can be accessed to form a digital data sequence that comprises numerous data steps, with each step defined by an 8 bit digital number from the RAM **404** that represents an incremental voltage level between 0 and 255. For example, a first step in a digital data sequence could be a data step at a level of 60, defined by an 8 bit digital value of 00111100, a second step in a digital data sequence could be a data step at a level of 112, defined by an 8 bit digital value of 01110000, and so on. As noted herein, the digital data sequence from each ADG RAM **404** can be accessed multiple times to generate multiple, temporally offset (i.e., delayed) digital data sequences that can then be further conditioned into nozzle-drive waveforms.

In general, the frequency operation of the ADG RAM **404** is a multiple of the number of delayed data sequences the RAM **404** is providing. For example, as shown in FIG. **4**, there are four phase read operations (P**1**, P**2**, P**3**, P**4**) performed on a selected ADG RAM **404-1** to generate four temporally offset (i.e., delayed with respect to one another) data sequences. Each phase P**1**, P**2**, P**3**, and P**4**, can be selected through a phase selector **408**, and each phase corresponds with the generation of a particular delayed or temporally offset digital data sequence that will be used to construct a nozzle-drive waveform for a particular nozzle **102**. Thus, a single ADG RAM **404** providing a single digital data sequence can be used to produce multiple delayed or temporally offset nozzle-drive waveforms to drive multiple nozzles. With the steps of each nozzle-drive waveform being updated at a 10 MHz clock frequency **410** (every 100 nanoseconds (nsec)), for example, the data sequences for each phase P**1**, P**2**, P**3**, and P**4**, that are being used to construct the nozzle-drive waveforms are also updating at a 10 MHz frequency. However, the ADG RAM **404-1** operates at a 40 MHz clock frequency **412** in order to provide each step of the digital source data from four RAM addresses (e.g., A**1**, A**2**, A**3**, A**4**) to the four phase read operations (P**1**, P**2**, P**3**, P**4**) which occur every 25 nsec. Each of the four data sequences built up through the four phase reads (P**1**, P**2**, P**3**, P**4**) will be identical, but will be temporally offset, or delayed, from one another. While examples are discussed herein with regard to four temporally offset data sequences generated through four phase read operations P**1**, P**2**, P**3**, and P**4**, from a single ADG RAM **404**, such examples are not intended to be limiting. In fact, other configurations are possible and contemplated herein. For example, in different implementations a single ADG RAM **404** providing a single digital data sequence can be used to produce a greater or fewer number of delayed or temporally offset nozzle-drive waveforms to drive multiple nozzles. In a particular example, a single digital data sequence from a single ADG RAM **404** might be used to produce ten delayed nozzle-drive waveforms to drive ten nozzles where each nozzle-drive waveform is updated at 10 MHz (every 100 nanoseconds (nsec)). In such a case, the ADG RAM **404** can operate at 100 MHz in order to provide each step of the digital source data to ten different phase read operations occurring every 10 nsec.

FIG. **5** shows an example of timing for a four phase read operation that can be used to read source data from a single ADG RAM **404**, such as ADG RAM **404-1**, and to generate four identical source data sequences **500** (illustrated as data sequences **500-1**, **500-2**, **500-3**, **500-4**) that are delayed, or temporally offset, from one another. Each data sequence **500** read by the four phases P**1**, P**2**, P**3**, and P**4**, can eventually be used to construct a corresponding nozzle-drive waveform signal to drive a print nozzle **102** on a MEMS die **104**. Referring to FIGS. **4** and **5**, in this example, the four phase read operations (P**1**, P**2**, P**3**, P**4**) are driven by a 40 MHz clock **412**, with each step of the digital source data sequence being updated on a 10 MHz clock **410**. That is, a data read at a particular address (e.g., A**1**) of the ADG RAM **404-1** can begin with phase P**1** via a phase selector **408**, for example, and then subsequent data reads at different addresses (e.g., A**2**, A**3**, A**4**) can be made by switching the phase selector **408** at 40 MHz through phases P**2**, P**3**, and P**4**. Thus, with each phase read operation, a portion (e.g., a digital data step) of each data sequence **500-1**, **500-2**, **500-3**, and **500-4**, is accessed as an 8 bit data value (i.e., 0 to 255) from the digital source data in ADG RAM **404-1** every 25 nanoseconds (nsec)), so that after 100 nsec, a single digital data step of each data sequence **500-1**, **500-2**, **500-3**, and **500-4**, has been generated for each phase. As shown in FIG. **4**, each phase (P**1**, P**2**, P**3**, P**4**) can read data from a different address (e.g., A**1**, A**2**, A**3**, A**4**) of the ADG RAM **404-1** using a separate bus line **414**. After the phase P**4** data is read, the address locations being read at the ADG RAM **404-1** can be updated and the next step of the source data sequence from the ADG RAM **404-1** can be read, beginning again with a phase P**1** read. This process continues as each digital data step or portion of each of the temporally offset (i.e., delayed) data sequences **500-1**, **500-2**, **500-3**, and **500-4**, is read from the ADG RAM **404-1**.

Referring still to FIGS. **4** and **5**, at a first time (e.g., t**1**), a first phase P**1** data read is made at an address A**1** of the ADG RAM **404-1**, which can result in an 8 bit data value that defines a first step **502-1** of a digital data sequence **500-1**. At a second time (e.g., 25 nsec later, at t**2**) following the first phase P**1**, a second P**2** data read is made at an address A**2** of the ADG RAM **404-1**, which can result in an 8 bit data value that defines a first step **502-2** of a delayed digital data sequence **500-2**. Data can be similarly read from the ADG RAM **404-1** at times t**3** and t**4** for steps **502-3** and **502-4** for phases P**3** and P**4**, respectively. Each step (e.g., **502**) of a digital source data sequence **500** can be defined as an 8 bit digital number read from ADG RAM **404-1** that represents a range of 0 to 255.

Referring again to FIG. **4**, in addition to ADG selector **406**, conditioner unit **405** can include a scaler **416**, also referred to as a nozzle scaling multiplier **416**. For each nozzle **102** of the MEMS die **104**, a particular nozzle scaling value **418** can be determined and stored on the ASIC **122**. A nozzle scaling value **418** can be selected for each nozzle **102** by a scaling selector **420**. While the steps of each nozzle-drive waveform are updated at a 10 MHz clock frequency **410** (every 100 nanoseconds (nsec)), for example, the multiplier **416** and scaling selector **420** operate at a higher frequency that is a multiple of the 10 MHz nozzle update frequency. The multiple is equal to the number of multiple delayed digital data sequences being generated from the ADG RAM **404** using phase selector **408**. In the FIG. **4** example, because four delayed digital data sequences are being generated, the multiplier **416** and scaling selector **420** operate/update at a 40 MHz rate (every 25 nsec). Operating the multiplier **416** at a higher frequency than the nozzle update frequency enables each multiplier to scale multiple nozzles **102**, and provides a corresponding reduction in the number of multipliers on the ASIC **122**. Thus, in the example of FIG. **4**, instead of having a separate multiplier to provide scaling for each nozzle **102**, each nozzle scaling multiplier **416** operating at 4 times the nozzle update frequency can provide scaling for four nozzles **102**, resulting in a four times reduction in the number of nozzle scaling multipliers **416** on the ASIC **122**.

A nozzle scaling multiplier **416** can scale each nozzle by multiplying each digital data step (i.e., the 8 bit digital data value) of a digital data sequence read from an ADG RAM **404** by a nozzle scaling value **418** (i.e., a numerical factor), such as by a percentage increase or a percentage decrease. For example, an 8 bit digital value of 01101110 representing a relative voltage level of 110 out of 256 levels, could be multiplied by a nozzle scaling value **418** of 1.10 (a 10% increase) to produce a scaled 8 bit digital value of 01111001 representing a relative voltage level of 121 out of 256 levels. Thus, the multiplier **416** can be used to alter the digital data sequences from the ADG RAMs **404-1**, **404-2**, . . . , **404**-*m*, that are to be used to construct nozzle-drive waveforms for each respective nozzle **102** that the ASIC die **122** or **124** controls.

A nozzle scaling value **418** can be determined for each nozzle **102** of the MEMS die **104**. For example, each nozzle **102** of the MEMS die **104** can be calibrated to determine variances due to manufacturing and/or processing tolerances. The calibration of each nozzle can be used to determine a nozzle scaling value **418** that scales a nozzle-drive waveform to achieve fluid drops that are uniform in size/volume and velocity for all nozzles **102**. This calibration can be performed periodically, such as daily, or per each use, or per each print job, and so on. The calibration can also be selectable by a user. The ASIC die **122** can store the scaling values **418** for each respective nozzle **102** that the ASIC die **122** controls. Digital data sequences being read at different phases (e.g., P**1**, P**2**, P**3**, P**4**) from the ADG RAMs **404-1**, **404-2**, . . . , **404**-*m*, to construct nozzle-drive waveforms for particular nozzles **102** can be scaled with the particular scaling values associated with those nozzles. Thus, the digital values of a data sequence generated by phase P**1** to be conditioned into a nozzle-drive waveform to drive a particular nozzle can be multiplied by a particular scaling value **418** associated with that particular nozzle. As shown in FIG. **4**, the scaling values **418** are updated to the multiplier **416** at the same rate (i.e., 40 MHz) that the phases P**1**, P**2**, P**3**, and P**4**, are switched. Thus, as a first step of a digital data sequence is read from an ADG RAM **404** in phase P**1**, the appropriate scaling value **418** for the nozzle to be driven using the P**1** data sequence is applied through the multiplier **416**. As each data read phase is advanced at a 40 MHz rate, so too are the scaling values **418** advanced and applied through the multiplier **416**.

In some examples, the scaling values **418** are predetermined at the time of manufacture during a calibration routine and stored on the ASIC **122** and **124**, as appropriate, depending on which nozzles are to be controlled by which ASIC. However, as noted above, nozzle calibrations can also be performed periodically, such as on a daily basis, before or during each use, before or during each print job, and so on. Thus, in some examples, the scaling values **418** are updateable during printing by a printing device. In other examples, a scaling value **418** of a nozzle is updateable based on scaling values **418** stored for adjacent nozzles. In still other examples, a scaling value of a nozzle can be updateable dynamically based on firing data being sent to an adjacent nozzle. Thus, a scaling value of a nozzle can be adjusted dynamically to compensate for the effect of an adjacent nozzle that is ejecting or about to eject a fluid ink drop.

FIG. **6** shows an example of an inkjet printing device (i.e., printer) **600** suitable for implementing a piezoelectric printhead assembly **100** that provides multiple delayed waveform signals to drive print nozzles on a MEMS die **104**. In this example, the inkjet printer **600** includes a print engine **602** having a controller **604**, a mounting assembly **606**, replaceable fluid supply device(s) **608**, a media transport assembly **610**, and at least one power supply **612** that provides power to the various electrical components of inkjet printer **600**. The inkjet printer **600** further includes a piezoelectric printhead assembly **100** to eject drops of ink or other fluid through a plurality of nozzles **102** toward print media **618** so as to print onto the media **618**. In some examples, a piezoelectric printhead assembly **100** can be an integral part of a supply device **608**, while in other examples a piezoelectric printhead assembly **100** can be mounted on a print bar (not shown) of mounting assembly **606** and coupled to a supply device **608** (e.g., via a tube). Print media **618** can be any type of suitable sheet or roll material, such as paper, card stock, transparencies, Mylar, polyester, plywood, foam board, fabric, canvas, and the like.

In the FIG. **6** example, a piezoelectric printhead assembly **100** uses a piezoelectric material actuator to generate pressure pulses that force ink drops out of a nozzle **102**. Nozzles **102** are typically arranged in one or more columns or arrays along a MEMS die **104** of assembly **100** such that properly sequenced ejection of ink from nozzles **102** causes characters, symbols, and/or other graphics or images to be printed on print media **618** as the printhead assembly **100** and print media **618** are moved relative to each other.

Mounting assembly **606** positions the printhead assembly **100** relative to media transport assembly **610**, and media transport assembly **610** positions print media **618** relative to printhead assembly **100**. Thus, a print zone **620** is defined adjacent to nozzles **102** in an area between printhead assembly **100** and print media **618**. In one example, print engine **602** is a scanning type print engine. As such, mounting assembly **606** includes a carriage for moving printhead assembly **100** relative to media transport assembly **610** to scan print media **618**. In another example, print engine **602** is a non-scanning type print engine. As such, mounting assembly **606** fixes printhead assembly **100** at a prescribed position relative to media transport assembly **610** while media transport assembly **610** positions print media **618** relative to printhead assembly **100**.

Electronic controller **604** typically includes components of a standard computing system such as a processor (CPU) **624**, a memory **626**, firmware, and other printer electronics for communicating with and controlling inkjet printhead assembly **100**, mounting assembly **606**, media transport assembly **610** and other functions of printer **600**. Memory **626** comprises a non-transitory machine-readable (e.g., computer/processor-readable) storage medium that can include any device or non-transitory medium able to store code, executable instructions, and/or data for use by a computer system. Thus, memory **626** can include, but is not limited to, volatile (i.e., RAM) and nonvolatile (e.g., ROM, hard disk, floppy disk, CD-ROM, etc.) memory components comprising computer/processor-readable media that provide for the storage of computer/processor-readable coded instructions, data structures, program modules, and other data for printer **600**. Electronic controller **604** receives data **622** from a host system, such as a computer, and temporarily stores the data **622** in a memory. Data **622** represents, for example, a document and/or file to be printed. Thus, data **622** forms a print job for inkjet printer **600** that includes print job commands and/or command parameters. Using data **622**, electronic controller **604** controls printhead assembly **100** to eject ink drops from nozzles **102** in a defined pattern that forms characters, symbols, and/or other graphics or images on print medium **618**.

FIG. **7** shows an example of a scanning type inkjet printer **600**, in which mounting assembly **606** includes a carriage **700** that scans piezoelectric printhead assembly **100** in forward and reverse passes across the width of the media page **618** in a generally horizontal manner, as indicated by horizontal arrows labeled A. Between carriage scans, the media page **618** is incrementally advanced by media transport assembly **610**, as indicated by the vertical arrows labeled B. Thus, media transport assembly **610** moves the media page **618** through the printer **600** along a print media path that properly positions media page **618** relative to printhead assembly **100** as drops of ink are ejected onto the media page **618**.

Media transport assembly **610** can include various mechanisms (not shown) that assist in advancing a media page **618** through a media path of printer **600**. These can include, for example, a variety of media advance rollers, a moving platform, a motor such as a DC servo motor or a stepper motor to power the media advance rollers and/or moving platform, combinations of such mechanisms, and so on.

In addition to carriage **700**, mounting assembly **606** includes a scanning sensor **702** fixed to the carriage **700**. In some examples, sensor **702** is a lightness/spot sensor that scans printed dots **704** on a media page **618** and measures reflectance from the media page **618** in order to enable a determination as to the sizes and positions of the dots **704**. As discussed herein below, such information can be analyzed by the printer **600** to determine the volume and velocity of fluid ink drops being ejected from nozzles **102** of the piezoelectric printhead assembly **100**. In some examples, sensor **702** comprises a light emitter to emit light onto the media page **618** and a light detector to detect light reflected off of the media page **618**. In some examples, sensor **702** comprises a light emitter and light detector that are positioned on either side of the carriage **700** and that travel along with the carriage to enable shining light through a print zone **610** to monitor fluid drops traversing a pathway from the printhead assembly **100** to the media page **618**. In some examples, sensor **702** comprises a light emitter and light detector that are part of the printer **600** and are positioned on either side of a media transport assembly **610** of the printer **600** to enable shining light through a print zone **610** to monitor fluid drops traversing a pathway from the printhead assembly **100** to the media page **618**. An analysis of the amount of light being blocked by fluid drops passing through the print zone **610** can provide information that can be analyzed by the printer **600** to determine the volume and velocity of fluid ink drops being ejected from nozzles **102** of the piezoelectric printhead assembly **100**. While particular sensors **702** and sensor configurations have been discussed, it should be understood that other types of sensing devices implemented in various configurations are possible and contemplated herein to gather fluid drop information that can be analyzed to determine fluid drop sizes, volumes, shapes, velocities, trajectories, and so on, as might be applicable to the calibration of nozzles **102** and the determination of scaling values **418** for nozzles **102**.

Referring again to FIG. **6**, controller **604** includes a nozzle calibration module **628** stored in memory **626**. Module **628** includes instructions executable on processor **624** to run a calibration routine that controls components of printer **600** and determines updated scaling values **418** for each nozzle **102** of a MEMS die **104** of a printhead assembly **100**. FIG. **8** shows a flow diagram that illustrates an example method **800** that corresponds with the calibration routine. Referring now generally to FIGS. **6**, **7**, and **8**, instructions from module **628** are executable to cause the printer **600** to print fluid ink drops from nozzles **102** of a piezoelectric printhead assembly **100** (block **802**, FIG. **8**). Printing the fluid drops can include controlling a single multiplier on a drive ASIC of the printhead assembly **100** to scale multiple nozzle-drive waveforms, where each of the nozzle-drive waveforms is scaled using a particular scaling value stored on the ASIC that corresponds with a particular nozzle. Instructions from module **628** are further executable to control a sensing device (e.g., on the printer or the printhead assembly) to detect and monitor the fluid drops to determine fluid drop characteristics such as drop volume and drop velocity (block **804**, FIG. **8**), and to calculate an updated scaling value for each nozzle based on the fluid drop characteristics (block **806**, FIG. **8**). As noted above, fluid drops can be monitored in a number of ways, such as monitoring the drops during their flight through a print zone, and/or monitoring the drops after they impact the media. Instructions from module **628** are then further executable to store the updated scaling values **418** on the ASIC of the piezoelectric printhead assembly **100** (block **808**, FIG. **8**).

Referring again to FIG. **4**, each digital data step (i.e., the 8 bit digital data value) of a digital data sequence read from an ADG RAM **404** that has been scaled by multiplier **416** is provided by the conditioner unit **405** to a storage register **422** (illustrated as registers R(**1**) **422-1**, R(**2**) **422-2**, R(**3**) **422-3**, R(**4**) **422-4**). Thus, each of the scaled digital data steps read from RAM **404** in phases P**1**, P**2**, P**3**, and P**4**, are stored in corresponding registers R(**1**) **422-1**, R(**2**) **422-2**, R(**3**) **422-3**, and R(**4**) **422-4**. The scaled digital data steps are held in the registers **422** until it is time to advance the digital data sequence from the ADG RAM **404** and read again using phase P**1**. When the next P**1** read occurs, the four scaled digital data steps are clocked out of the registers **422** and into digital-to-analog converters (DACs) **424** (illustrated as DACs **424-1**, **424-2**, **424-3**, **424-4**, . . . , **424-*p***). Thus, the ASIC die **122** can include a number of DACs, **424-1**, **424-2**, **424-3**, **424-4**, . . . , **424-*p***, where p is an integer value. For instance, p can have a value equal to one half of a number of nozzles **102** of a MEMS die **104** to which the ASIC **122** is wire bonded. Thus, there can be a respective DAC **424** for each nozzle **102** that the ASIC die **122** controls. Each of the number of DACs **424** can receive a respective, scaled, digital data step or portion of a digital data sequence stream, such as from the data step outputs **421** from storage registers R(**1**) **422-1**, R(**2**) **422-2**, R(**3**) **422-3**, and R(**4**) **422-4**, and can convert these scaled, digital data step outputs **421** into analog voltage step outputs **426**. The digital data step outputs **421** are low voltage digital voltage levels on the order of 1 to 3 volts, and the DACs can convert the digital data step outputs **421** to low voltage analog voltage step outputs **426** in the range of about 1 to 3 analog volts. Each respective low voltage analog voltage step output **426** can be sent to a respective driver amplifier **400** (i.e., amplifier **400-1**, **400-2**, **400-3**, **400-4**, . . . , **400-*n***), where the low voltage analog voltage step output **426** can be amplified to a full nozzle-drive voltage in the range of about 10 to 30 volts.

The ASIC die **122** can include a control sequencer **428**. The control sequencer **428** can store and provide digital control sequences such as a fire cycle sequence corresponding to the operation of the amplifier **400**, for each of the respective driver amplifiers **400-1**, **400-2**, **400-3**, **400-4**, . . . , **400-*n***. For example, a fire cycle can begin with the control sequencer **428** resetting drive circuits for each respective nozzle **102** that the ASIC die **122** controls. Amplifier control sequences stored by the control sequencer **428** can be loaded for each respective nozzle **102** that the ASIC die **122** controls. Amplifier calibration data per nozzle can also be loaded for each respective nozzle **102** that the ASIC die **122** controls. Selected digital data sequences from an ADG RAM **404** that have been conditioned and converted into corresponding nozzle-drive waveforms can be loaded for nozzles that are firing in a particular firing cycle, and non-firing nozzles can be driven at the rest voltage.

Similarly, as noted above, a second ASIC die **124** can include the same components of ASIC die **122**, and thereby can control nozzles **102** of the MEMS die **104** with a unique nozzle-drive waveform generated at each nozzle **102**.

What is claimed is:

**1**. A piezoelectric printhead assembly comprising:

a single micro-electro mechanical system (MEMS) die including a first side having a first half of a plurality of nozzles and a second side having a second half of the plurality of nozzles;

a first application-specific integrated circuit (ASIC) die adjacent to the first side of the single MEMS die and coupled to the first half of the plurality of nozzles;

a second ASIC die adjacent to the second side of the single MEMS die and coupled to the second half of the plurality of nozzles;

a first arbitrary data generator (ADG) on the first ASIC to provide a first digital data sequence;

a first multiplier on the first ASIC to scale the first digital data sequence by a scaling factor associated with a nozzle on the first side of the single MEMS die;

a second ADG on the second ASIC to provide a second digital data sequence; and,

a second multiplier on the second ASIC to scale the second digital data sequence by a scaling factor associated with a nozzle on the second side of the single MEMS die.

**2**. A piezoelectric printhead assembly as in claim **1**, wherein:

the first ASIC comprises a plurality of nozzle scaling values each corresponding with a nozzle on the first side of the single MEMS die; and,

the second ASIC comprises a plurality of nozzle scaling values each corresponding with a nozzle on the second side of the single MEMS die.

**3**. A piezoelectric printhead assembly as in claim **2**, further comprising:

a scaling selector to select a scaling value from a plurality of nozzle scaling values, wherein the selected scaling value corresponds with a particular nozzle and a multiplier is to multiply the selected scaling value by a digital data sequence that corresponds with the particular nozzle.

**4**. A piezoelectric printhead assembly as in claim **2**, wherein each nozzle scaling value comprises a calibration value to scale a nozzle-drive waveform of a particular nozzle to achieve a uniform volume and velocity of a fluid drop from the particular nozzle.

**5**. A piezoelectric printhead assembly as in claim **2**, wherein each nozzle scaling value can be periodically updated based on an observation of a fluid drop ejected from a nozzle corresponding with the nozzle scaling value.

**6**. A piezoelectric printhead assembly comprising:

a single micro-electro mechanical system (MEMS) die including a plurality of nozzles;

a first and a second application-specific integrated circuit (ASIC) coupled, respectively, to a first side and a second side of the single MEMS die by respective first and second pluralities of wire bonds, wherein each of the first plurality of wire bonds corresponds to a respective nozzle of a first number of the plurality of nozzles on the first side and each of the second plurality of wire bonds corresponds to a respective nozzle of a second number of the plurality of nozzles on the second side; and,

on each ASIC:

a plurality of arbitrary data generators (ADGs), each ADG selectable by an ADG selector to provide a digital data sequence;

a phase selector to select a plurality of phases of the digital data sequence, each phase corresponding with a temporally offset version of the digital data sequence to construct multiple delayed digital data sequences from a selected ADG; and

a multiplier to scale the multiple delayed digital data sequences.

**7**. A piezoelectric printhead assembly as in claim **6**, further comprising:

first and second pluralities of nozzle scaling values stored, respectively, on the first and second ASICs, each nozzle scaling value corresponding with a particular nozzle of the single MEMS die.

**8**. A piezoelectric printhead assembly as in claim **7**, further comprising:

a scaling selector to select a nozzle scaling value for multiplication by the multiplier against a particular one of the multiple delayed digital data sequences.

**9**. A piezoelectric printhead assembly as in claim **8**, wherein the selected nozzle scaling value and the particular one of the multiple delayed digital data sequences both correspond to a particular nozzle on the single MEMS die.

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